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USES OF PETROLEUM PRODUCTS IN SPACE EXPLORATION

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ABSTRACT

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A continued use for hydrocarbons is foreseen as a propellant for the lower stages of rocket vehicles. For the upper stages the hydrogen propellant may come from petroleum sources. Hydrocarbon lubricants may also be required in space vehicles because of their superior resistance to radiation damage. This same resistance suggests the use of hydrocarbons as heat-transfer fluids and as plastic and elastomeric materials of construction. Finally it is suggested that hydrocarbons are ideal space-storable reducing agents and that man may establish refueling stations on the moon or on Mars.

AUTHOR

INTRODUCTION

While petroleum products have many desirable attributes, the most attractive has been their low cost. This is due to the low cost of the raw material, relatively inexpensive processing and very easy transportation. But in considering the role of petroleum products in space applications, the cost factor becomes quite unimportant since the overall costs of these programs are orders of magnitude higher than that of the materials used therein. Therefore petroleum products must win their places in the space program by virtue of unique properties which fulfill an essential need and not because they may be cents or dollars per gallon cheaper than other materials.

This paper summarizes the present and probable future use of petroleum products as a rocket propellant. It compares hydrocarbons with other materials as space lubricants and as heat transfer fluids and indicates those properties where hydrocarbons excell. The paper also suggests possible applications of hydrocarbon polymeric and elastomeric materials of construction and finally suggests that hydrocarbons may fill a need for a space-storable reducing agent.

HYDROCARBON PROPELLANTS

Petroleum derived fuels, usually of the kerosine type, have been widely used as a rocket propellant for many years. They have usually been paired with liquid oxygen in these applications. The Thor, Atlas, and the bottom Saturn stages are examples of launch vehicles that use hydrocarbon and liquid oxygen.

The low-aromatic kerosine type fuel that is used in the United States as a rocket propellant is covered by the specification MIL-R-25576, grade RP-1, ~~and is~~ reproduced in part below:

10 percent evaporated	365 - 410° F
90 percent evaporated	525° F, max
Flash point	110° F, min
Viscosity at -30° F, cs	16.5 max
Sulfur, wt percent	0.05 max
Aromatics, vol. percent	5 max
Olefins, vol. percent	1 max
Gravity, ° API	42-45

A comparison of the performance of RP-1 and oxygen with a few other propellant systems is given in figure 1 (ref. 1, pg. 3). In this figure the velocity increment attainable per stage is shown as a function of specific impulse for several propellant weight fractions ranging between 0.60 and 0.95. A velocity of about 30×10^3 ft/sec is required to attain earth orbit and about 60×10^3 ft/sec for a lunar landing and return mission. Also indicated on the abcissa are the performances, in terms of impulse, for several rocket systems including RP-1 and oxygen.

Velocity increments sufficient to acquire earth orbit can be obtained with single stage vehicles but require both quite high impulses and very low payload and structure weights (very high propellant weight fractions). More difficult missions can not be accomplished in a single stage and for this reason multistaged rockets are used with each adding only a portion of the required total velocity increment.

Figure 1 shows that for modestly designed vehicles, for example those having only 60 percent propellant and 40 percent payload and structure, that the slope is not great and that the lower impulse RP-1 oxygen system is not too much inferior to such high energy propellants as hydrogen-oxygen. But for the more sophisticated vehicles, those having very light structures and power plants and very large propellant weight fractions, there are great benefits to be derived from using high-energy systems. This is especially true for the upper stages of a multi-stage system.

Consider, for example, a four-stage rocket system. Assume, for purposes of this consideration, that each suceeding stage is one-fourth the mass of the preceding one. Then each extra pound of second stage generates a requirement of an additional 4 pounds of first stage equipment. In the fourth stage a saving of 1 pound can save 64 pounds in the first stage, 16 pounds in stage 2, and 4 pounds in stage 3 - a total of 85 pounds in the entire vehicle. It thus becomes clear that from an economic standpoint refinement of stage weight is increasingly justified in ascending stages. Since 3 pounds of liquid oxygen and liquid hydrogen produce nearly the same impulse as 4 pounds of liquid oxygen and kerosene, it is also clear that the choice of the higher impulse propellants is an effective method to save upper stage weight (ref. (2)).

It might appear that the lower energy hydrocarbon-oxygen propellant system would not be used in any stage. However, there are economic factors, largely related to the costs of developing rocket engines that must be considered in selecting propellants for new, very large engines. The F-1 engine is now being developed to deliver 1,500,000 pounds of thrust; five of these will be used for the bottom stage of the Saturn-5 vehicle (ref. 2). A full duration firing of this stage would consume $100,000 of propellants even though kerosene and liquid oxygen cost only $0.02 per pound. But the cost of these propellants is negligable compared to the cost of developing the engine. The United States has had a great deal of experience with the hydrocarbon-oxygen propellant system and practically all of the 54 satellite and space probe launched from the States in 1962 were accomplished with vehicles using these propellants in the bottom stage (ref. 3). In spite of this experience, it is estimated that it will take about 1000 firings of the F-1 engine before it is qualified for the launch of a manned vehicle (ref. 2). This engine is a very complex machine weighing about 20,000 pounds and a large number will be partially or totally destroyed in the test program. Therefore the best understood propellant system, hydrocarbon - oxygen, is being used for the most expensive bottom stages and the higher energy hydrogen-oxygen propellant system will be used for the upper stages where the greater gains in performance are attained.

The petroleum industry may also be involved in supplying the hydrogen both for the high energy chemical rockets and for the nuclear rocket which may follow chemical propulsion systems. The nuclear rocket will use hydrogen as the working fluid (ref. 1, pg. 63). The amount of hydrogen required for the development of these systems is not insignificant. Nearly 100 tons a day of liquid hydrogen are now being produced in the United States, mostly for space propulsion programs. This demand is sure to grow and may be supplied from petroleum sources using processes described at another session of this Congress.

In summary, industry will continue to supply the kerosine type fuels that are used in lower stage propulsion. It may be asked to supply, in greatly increasing quantities, the hydrogen that is used in the development and flight of high energy chemical and nuclear rocket upper stages.

HYDROCARBON LUBRICANTS

The new problems in lubrication that arise from the space environment are primarily the results of low pressures and, to a lesser and varying extent, the presence of ionizing radiation. Earth orbiting satellites are exposed to pressures down to 10^{-13} torr and deep space probes to considerably lower pressures; the attendant problems are summarized in reference 4.

The radiation environment is discussed in reference 5. This section compares hydrocarbon oils with other lubricants in regards to their rates of evaporation at low pressures and their resistance to damage by ionizing radiation. Such other aspects of lubrication as viscosity and viscosity index, thermal stability and lubricity are not discussed since these factors are common to both terrestrial and space applications.

The requirement for very low vapor pressures can be met by many of the fluids that have been used in high vacuum technology; the Apiezon oils and greases are examples. Several studies have been made of the evaporation rates of fluids at low pressures and the results from one of these is shown in figure 2 (ref. 4). In this figure an ester, a polyphenyl ether, a polysiloxane and a hydrocarbon mineral oil are compared. The mineral oil is a highly refined, naphthenic base material with the low boiling fractions removed. It is seen that, for this group of materials, that the hydrocarbon (mineral) oil has the lowest evaporation rate at temperatures below 150° F and that the siloxane has the lowest rate of temperatures above 200° F. This suggests that hydrocarbon oils can either excell or be competitive with the synthetic lubricants for many space applications where low evaporation rates are required.

However low vapor pressures and low evaporation rates, per se, are not all important to space lubrication since mechanical design can circumvent the need for very low vapor pressure as shown in figure 3 (ref. 4). Shown is a part of the Tiros weather satellite where it is required that the mirror turn at 2750 rpm for several thousand hours. The rolling contact bearing needs only a very thin film of lubricant and this is maintained from reserves soaked into porous media. The important point in this design are the narrow clearance passages that separate the bearing from space vacuum. If the vapor pressure of the lubricant is only moderately low, 10^{-6} torr for example, then oil can escape only through molecular beam flow. And with the relatively long and close clearance passages of this design the molecular flow is of the order of 1 gram per year even though the external pressure is of the order of 10^{-12} torr. In fact the oil loss rate is independent of the external pressure.

While hydrocarbon lubricants offer no unique values in regard to meeting the low pressure requirements for space lubrication, they are clearly superior to other lubricants in their resistance to radiation damage. This is shown by data taken from reference 6 and reproduced in table I. It is seen that polynuclear aromatics are the most resistant to radiation damage although this type material is certainly inferior in terms of viscosity index and perhaps other desired properties. However the mineral oil shown in table I is better than some of the other candidate lubricants and would also have good qualities otherwise.

Therefore, if resistance to radiation is the most important requirement, the hydrocarbon lubricants and especially the polynuclear aromatics may be used. An example of such a requirement would be a long-lived satellite operating in the Van Allen belts.

OTHER APPLICATIONS

Closely related to lubricants are the fluids which might be used as heat transfer media. There are several space power systems and space vehicles, either under development or in the early planning stages, that require a heat transfer loop. The sources of this heat may be a nuclear pile, a radioisotope source, or focussed solar radiation. The uses of this heat vary. The properties sought for in the heat transfer fluid are thermal and radiation stability, freedom from corrosion, a wide liquidus range, and possibly some lubricating qualities.

For very high temperature service and for the high radiation fluxes usually encountered in nuclear systems, only the liquid metals have the required thermal and radiation stability. Mercury and the alkali metals are being considered for such service. The primary problem encountered in the use of these metals is one of corrosion.

Organic fluids can be used at lower temperatures, up to perhaps 800° F, and for systems where the total radiation dosage is not too high. As shown in table I, the polynuclear aromatics are the most resistant of the organic compounds to radiation damage and will withstand dosages of the order of 10^9 to 10^{10} rads before viscosity changes exceed 25 percent. However, small quantities of gas are generated at lower dosages and this can be very troublesome in some applications. The polynuclear aromatics are also among the most thermally stable organic compounds and present, of course, little or no problem in regard to corrosion. In summary petroleum derived hydrocarbon fluids, especially the polynuclear aromatics, are strong candidates as heat transfer fluids for some possible space applications.

Another area to consider are the possible space application of hydrocarbon plastics and elastomers. Again their principle virtue is that of radiation resistance as shown in table II taken from reference 6. Polystyrene is outstanding in this regard.

A specific example of the use of an organic plastic is in encapsulating a new type of solar cell. The electric power for practically all the satellites and space probes is supplied by batteries and solar cells. The silicon solar cells have proven themselves very long lived and reliable. For example the Vanguard satellite that was launched in March 1958 is still transmitting after more than 5 years. These silicon solar cells are ideal for moderate power levels up to perhaps a few hundred watts. However at higher powers the necessity for using rigid panels presents mechanically embarrassing problems in that it is very difficult to fold them up for launch.

Therefore thin film cells are being made and evaluated. An example is shown on figure 4, (ref. 1, pg. 130). Cadmium sulfide is the photovoltaic material. Compared in figure 4 are a conventional cell and a thin film cell, each designed to supply 1 kilowatt of power. The conventional silicon cell array will require about 30,000 individual cells supported on a rigid structure. Because of the lower efficiency, the cadmium sulfide array is about five times greater in area; however the weight of this larger area, thin-film system is slightly less than for a silicon panel having the same power output. In addition the thin film cells can be made in much larger area units so that only 2000 film cells 6 inches square are required. These cells are made by the vacuum evaporation of photovoltaic materials on foils or metallized plastic and are encapsulated in plastic. It is hoped that these can be furled for launch and then deployed in space.

The most desired property for the plastic used in these cells is continued transmittance to that portion of the sunlight that is used in the photovoltaic process. This varies somewhat with the photovaltaic semiconductor but, in general, high transmittance between 0.4 and 1.2 microns is desired. Changes in mechanical properties through exposure to the space environment is of lesser importance since, once deployed, there is substantially no stress imposed on the array. Hydrocarbon plastics such as polystyrene and polyethylene may prove superior for this thin film photovoltaic application.

Another example of a proposed use of polymeric materials is in space erectable structures. Studies have been made of an inflatable earth-orbiting laboratory that would house several people. The mechanical properties of the plastic would be more important and the optical properties much less so in this case.

Finally there is the possible future use of petroleum derived hydrocarbons as space-storable reducing agents. It may become necessary to store chemical energy sources in Earth or moon orbit, on the moon or on Mars. This material might find use as a fuel for roving vehicles on the lunar or planetary surface, as a reactant for fuel cells or as a rocket propellant. The fuel should be noncorrosive, stable to the space environment, and be a low vapor pressure liquid at space temperatures. Equilibrium temperatures in space range between -50° to $+200^{\circ}$ F for distances between Venus and Mars. Petroleum fractions can be selected that would be easily stored at these temperatures.

Of course, an oxidizing agent would also be needed but there is oxygen combined in the minerals of the moon or Mars. And, with abundant nuclear power assumed to be available and with the necessary processing plant, it may become feasible to separate and liquefy this oxygen. However, no liquid reducing agent can be obtained from minerals. Therefore it is suggested man may someday store hydrocarbon reserves in most distant places.

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TABLE I. - RADIATION STABILITY OF LUBRICANTS AND COOLANTS

[From Carroll and Bolt, ref. 6]

Polyphenyls	5000
Poly (phenyl ethers)	4000
Alkyl aromatics	1000
Mineral oils	100
Polyglycols	100
Methyl phenyl silicones	100
Aryl esters	100
Silicates	50
Disiloxanes	50
Alkyl diesters	50
Phosphates	5
Alkyl silicones	5
Olefins	5

Numbers are the radiation dose, in units of 10^6 rads for an approximate 25 percent change in viscosity or acidity.

TABLE II. - RADIATION STABILITY OF PLASTICS AND ELASTOMERS

[From Carroll and Bolt, ref. 6)

Plastics		Elastomers	
Polystyrene	4000	Polyethylene	90
Polyethylene	90	Polyisoprene	25
Urea-formaldehyde	50	Styrene-butadiene	10
Chlorotrifluoroethylene	20	Nitrile	7
Vinyl chloride	10	Neoprene	6
Cellulose acetate	10	Silicone	6
Phenol-formaldehyde	10	Butyl	4
Methyl methacrylate	10	Fluoro	4
Ester	1	Acrylates	3
Tetrafluorethylene	1	Sulfides	2

Numbers are radiation dose, in units of 10^6 rads for an approximate 25 percent change in tensile strength.

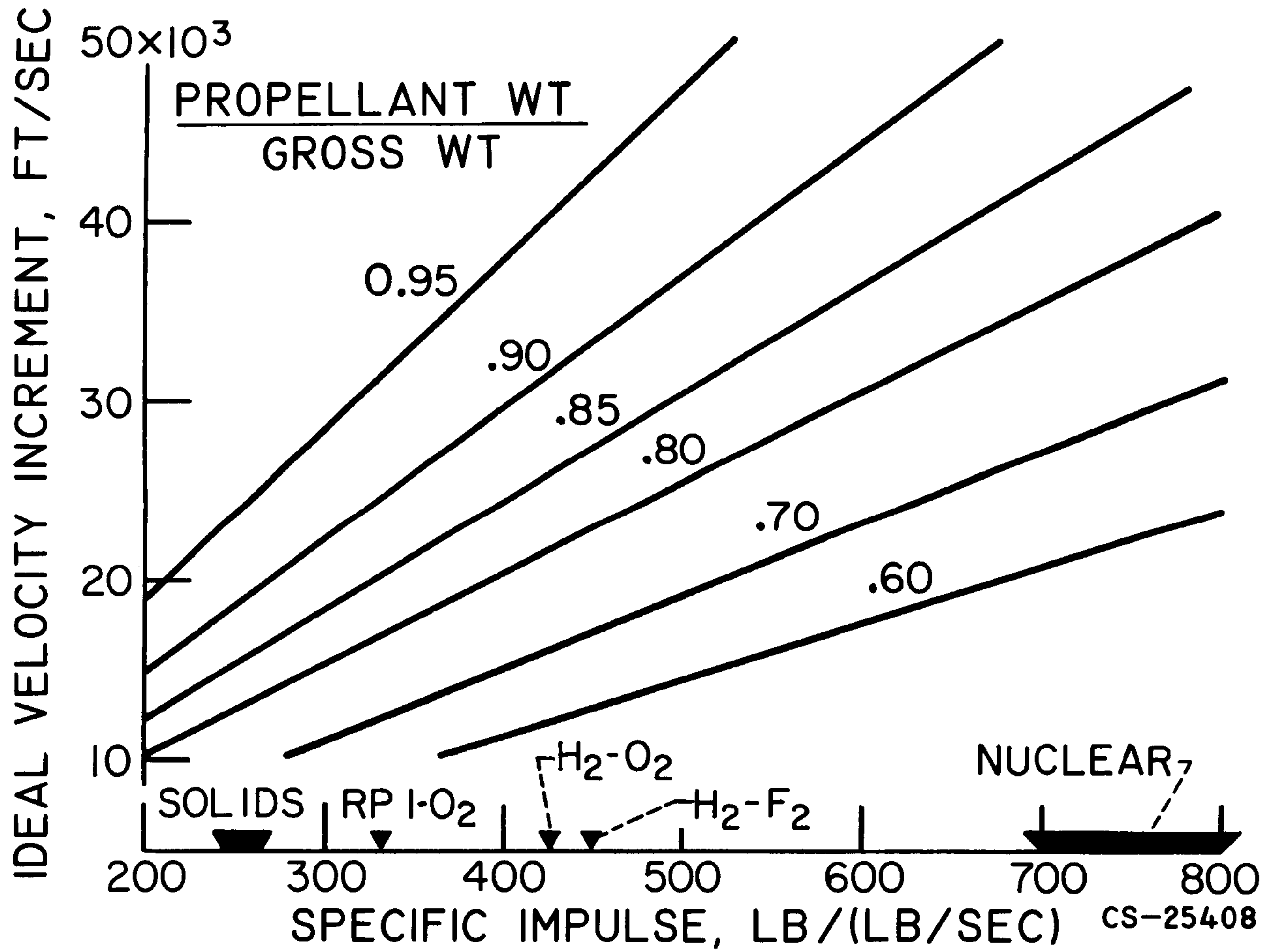

Figure 1. - Rocket vehicle performance.

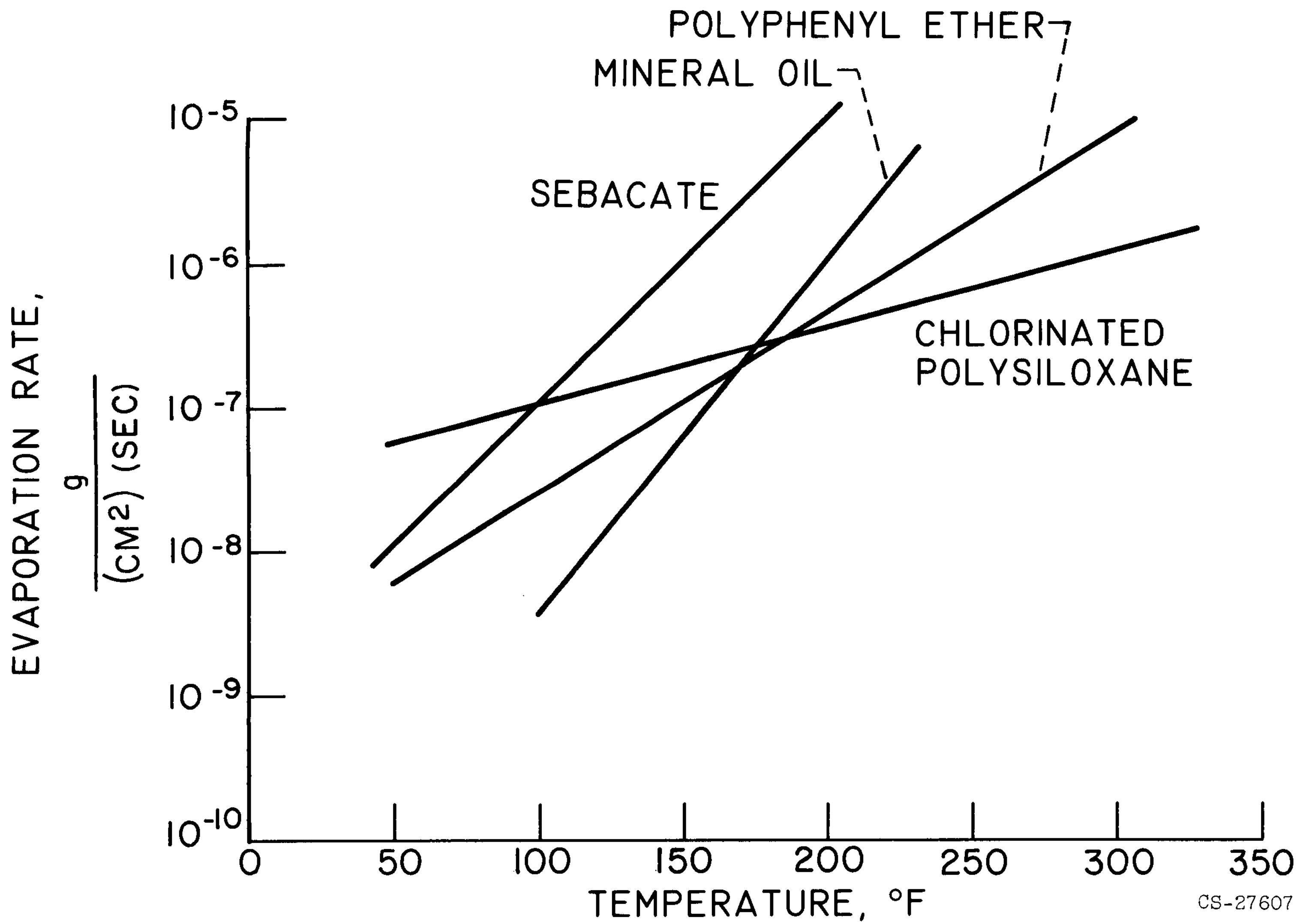

Figure 2. - Evaporation rates of several liquid lubricants at 10^{-6} to 10^{-7} torr.

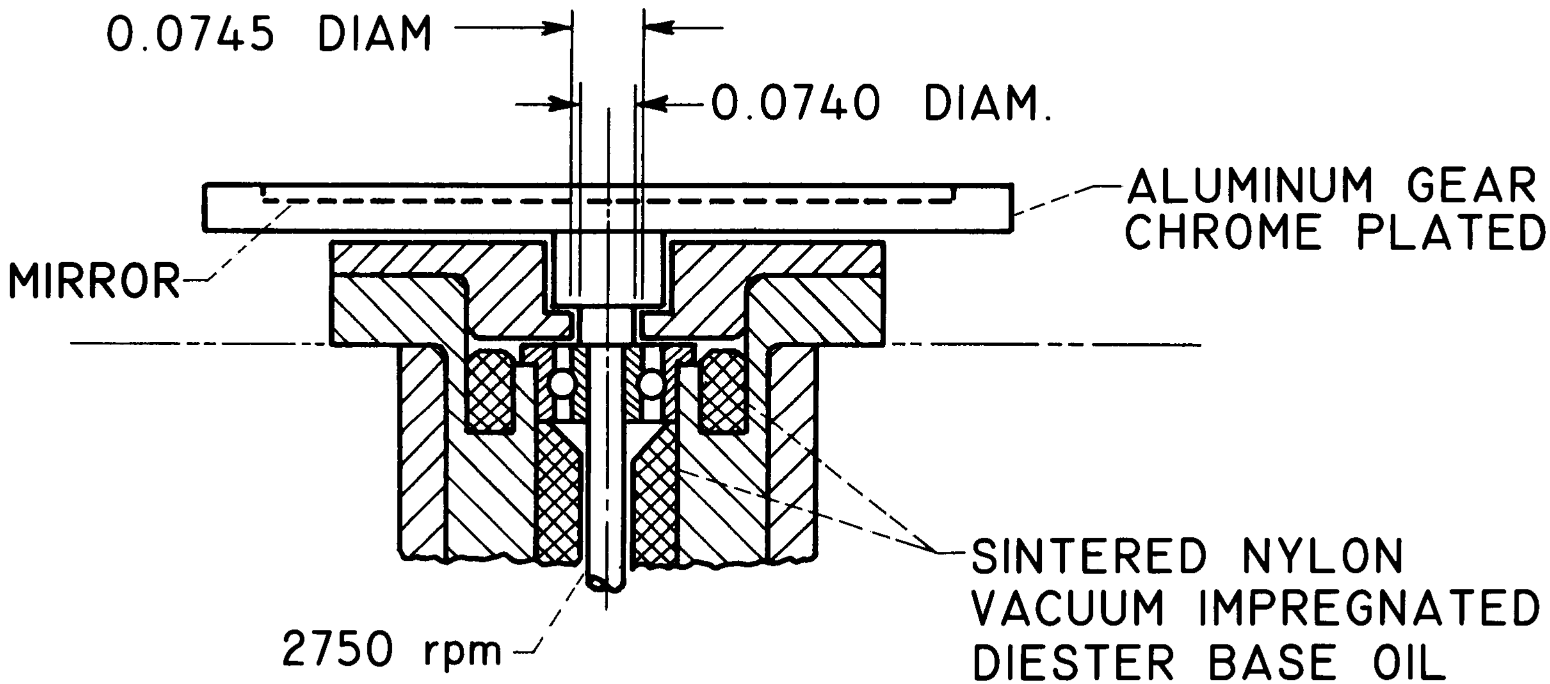

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Figure 3. - Tiros II radiometer spindle assembly.

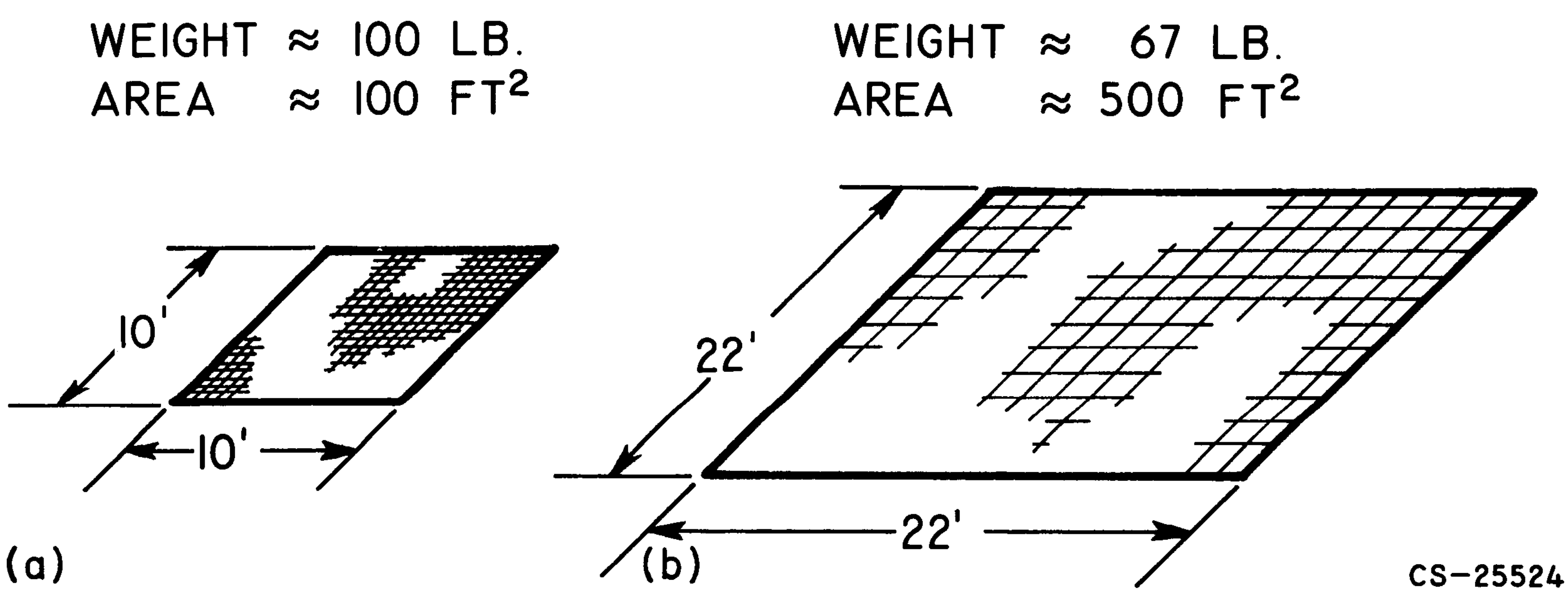

Figure 4. - Comparison of two types of 1-kilowatt solar cell arrays.